# Energy-critical minerals in the UK and Ireland: Molybdenum in fault systems

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**Project Highlights:**

- A truly multiscale approach to the application of structural geology to critical minerals;
- Focus on Molybdenum as a material with elevated criticality and expected increase in demand for use in clean energy technologies;
- The integration of Environmental, Social and Governance, and sustainability considerations into a geoscience project early in the discovery stage.

**Overview:**

Society is built on rock from which we source critical minerals (CM) that are essential for renewable energy infrastructure (wind turbines, solar panels, batteries), transport, mobile devices and medical equipment. Due to complex combinations of economic, geopolitical and logistic factors, CM are at risk of short supply. Materials recycling is moving forward, but significant amounts of CM are needed to tackle global environmental challenges and net zero. Molybdenum (Mo) is a rare heavy trace element that is recognised as a mineral with elevated criticality in the UK Criticality Assessment (Lusty 2021). It is used in steel alloys to improve their strength and wear resistance, and as a catalyst in the evolution reaction of hydrogen. It is essential for life as it enables nitrogen uptake in animals and plants. Molybdenite ($MoS_2$) is the main ore of molybdenum. In the UK, Mo is associated with orogenic, magmatic, and hydrothermal ore deposits and it is typically a by-product of copper and gold mining (Deady 2023). Previous studies have focussed on the geochemistry and dating of Mo, however there is a clear gap in our understanding of the controls of regional structures and associated deformation mechanisms on Mo occurrences and microstructures (Figure 1). The project will fill this gap through field mapping of structures and sampling in the Galway Granite Complex, western Ireland (Feely et al. 2020), the Newry Igneous Complex (Cooper 2016) and Curraghinalt orogenic deposits (Rice et al. 2016), Northern Ireland, and in south-west Scotland (Stone 2012) or the central-western Grampian Highlands (e.g. Smith et al. 2022), where Mo occurrences have been reported. Advanced quantitative analyses of microstructures, mineralogy and timing of events will help determine those deformation mechanisms that may have concentrated Mo-bearing minerals in each of the regions of interest. Early assessment of Environmental, Social and Governance (ESG) risks associated with potential Mo extraction will be undertaken in regions of high Mo concentrations. Data will be gathered through review of publications, reports and interviews and results will complement the project outcomes on Mo prospectivity, providing a sustainability framework for Mo from the early stages of discovery (Verrier et al. 2022).

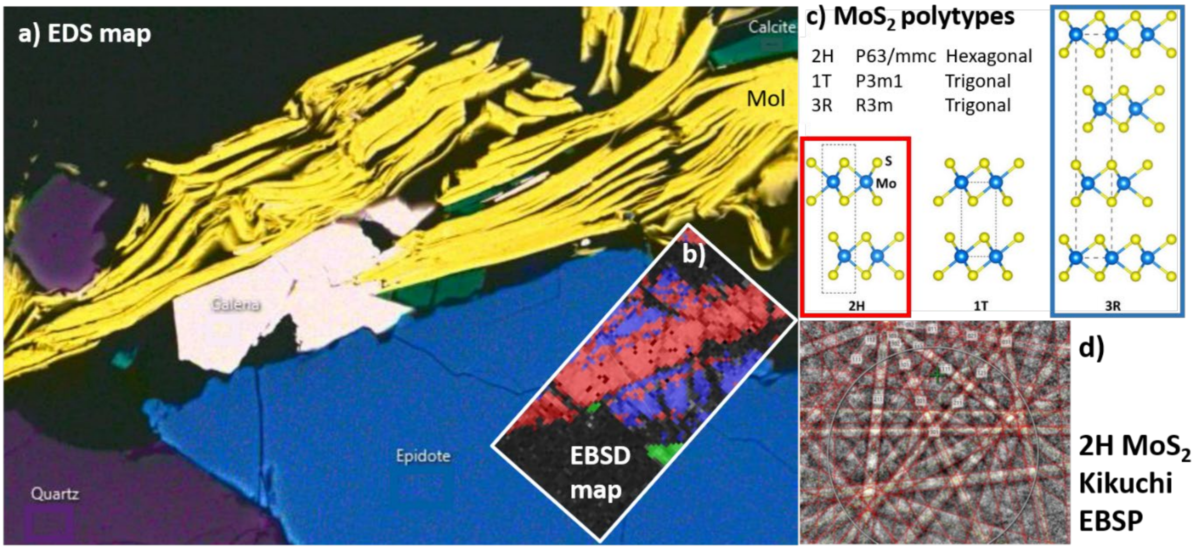


*Figure 1: a) Energy dispersive spectroscopy (EDS) map showing vein mineralogy in Galway granite (yellow = molybdenite, pink = galena, blue = epidote, purple = quartz and green = calcite); b) Electron backscatter diffraction (EBSD) map of $MoS_2$ demonstrating the occurrence of both 2H (red) and 3R (blue) polytypes; c) Atomic crystal structure of 2H, 1T and 3R $MoS_2$ polytypes showing respective space groups (left to right); d) 2H $MoS_2$ kikuchi pattern (EBSP) correctly indexed by simulation (red overlay). $MoS_2$ 2H or 3R polytype occurrence has direct influence on Mo recovery and processing.*

**Alt text for Figure 1:**

**Figure 1 is used in a geoscience PhD project summary to describe two different forms of the sheet-like structure of the mineral molybdenite.**

**Methodology:**

The successful candidate will use a top-down approach (field to nanoscale) to the study of structural controls on Mo mineralisation in the UK and Ireland. Fieldwork will be undertaken using detailed structural mapping, and portable (e.g. hand-held XRF) and drone technologies. Field data will be integrated with the Tellus Survey geophysical and geochemical data and modelled using Leapfrog and FracPaQ software to quantify fault/shear zone trends. Sampling will be carried out strategically across/along structural trends at locations of Mo occurrences. In the laboratory samples' microstructures and mineralogy will be studied with state-of-the-art microscopy (EBSD, EDS, EMPA, TEM) and LA-ICPMS techniques. The mechanical properties of Mo will be measured using nanoindentation. The student will gather evidence in the field on ESG risks and sustainability associated with identified regions of interest for Mo extraction by researching existing publications and reports, and through interviews with local communities, businesses and authorities.

**Possible Timeline**

Year 1: Fieldwork in the Galway area of western Ireland and in the Sperrin and Mourne Mountains of Northern Ireland. Field data modelling and sample collection for laboratory analyses. ESG/sustainability document review and interviews. Study of existing Galway granite core and sourcing of new core (BGS, SLR Ireland). Manuscript drafting.

Year 2: Advanced electron microscopy analyses, trace and major element geochemistry and mechanical testing of Irish samples. Fieldwork in south-western Scotland or central Highlands, field data modelling and sample collection for laboratory analyses. ESG/sustainability document review and interviews. Comparison with results from Ireland and Northern Ireland. Manuscript writing and submission, Thesis writing.

Year 3: ESG risks and sustainability data processing, analysis and evaluation for specific areas identified from the interpretation of results in Year 1 and 2. Completion of outstanding laboratory analyses and integration of datasets, results and interpretations. Manuscript submission and Thesis write-up.

The successful candidate will attend and present at at-least 2 national and 1 international conferences. The student will meet with the primary supervisory team once per week to discuss progress and receive guidance. They will meet with secondary supervisors every 3 months (online or in-person) The timeline remains flexible and will be adapted to optimise the work strategy in real-time, based on findings, and through regular cycles of reflection on data collection, results, interpretations, summaries, evaluations and planning that will be carried out by the student and the supervisory team.

**Training and skills:**

TARGET researchers will participate in a minimum of 40 days training over the 3.5 years of study composed of:

- an annual one-week workshop dedicated to their year group, and tailored to that cohort's needs in terms of skills development – *for the first three years of their study*;
- an annual all-TARGET workshop with cross-year interactions, advanced training and opportunities to specialise in particular areas – *all years of study*;
- a number of one-day workshops;
- additional online events and in-person workshops attached to relevant conferences.

Training in structural mapping and field data modelling will be delivered by the supervisory team in Year 1. Training in advanced electron microscopy, geochemistry and mechanical testing will be delivered at the Universities of Liverpool, Exeter and Leicester in Year 1 and 2. Training and guidance on the assessment of ESG risks and sustainability will be provided by UoE, UoLiv and SLR. The student will become expert in:

- Advanced structural geology techniques and their application to critical mineral discovery;
- The early evaluation of ESG and sustainability in the context of a discovery project.

**Partners and collaboration (including CASE):**

The student will visit the 2nd TARGET Partner (UoE) to perform quantitative chemical analyses using EMPA, and other TARGET collaborators (University of Leicester and BGS) to use correlative methods for micro-CT analyses and access the core store. Tektonik Consulting will host the student for a maximum of 6 weeks internship during which training in multiple dataset handling using Leapfrog software will be provided. SLR Consulting, our CASE partner, will deliver workshops and support an internship to provide the student with understanding of ESG and sustainability challenges in the various stages of a mining project.

**Further reading:**

Cooper, M. R., Anderson, P., Condon, D.J., Stevenson, C.T.E., Ellam, R.M., Meighan, I.G. and Crowley, Q.G. (2016) Shape and intrusion history of the Late Caledonian, Newry Igneous Complex, Northern Ireland. in Young, M. E., (ed.) *Unearthed: impacts of the Tellus surveys of the north of Ireland*,Dublin: Royal Irish Academy.

Deady, E., Goodenough, KM, Currie, D, Lacinska, A, Grant, H, Patton, M, Cooper, M, Josso, P, Shaw RA, Everett P, and Bide T (2023) Potential for Critical Raw Material Prospectivity in the UK. in: British Geological Survey. pp. 57pp.

Feely, M., Costanzo, A., Gaynor, S. P., Selby, D. and McNulty, E. (2020) A review of molybdenite, and fluorite mineralisation in Caledonian granite basement, western Ireland, incorporating new field and fluid inclusion studies, and Re-Os and U-Pb geochronology. *Lithos, 354-355*.

Stone, P., McMillan, A A, Floyd, J D, Barnes, R P, and Phillips, E R. (2012) Metalliferous and associated minerals resources, Southern Uplands. in *British regional geology: South of Scotland. Fourth edition*, Keyworth, Nottingham. British Geological Survey.

Verrier, B., Smith, C., Yahyaei, M., Ziemski, M., Forbes, G., Witt, K. and Azadi, M. (2022) Beyond the social license to operate: Whole system approaches for a socially responsible mining industry. *Energy Research and Social Science, 83*.

**Further details:**

Please visit https://target.le.ac.uk/ for additional details on how to apply.

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